Institute of Paper Science and Technology
Atlanta, Georgia

IPST TECHNICAL PAPER SERIES

NUMBER 485

THE EFFECT OF BASIS WEIGHT AND FREENESS ON SHEET PERMEABILITY AND CRITICAL IMPULSE DRYING TEMPERATURE

J. BOERNER AND D. ORLOFF

MAY 1993

The Effect of Basis Weight and Freeness on Sheet Permeability and Critical Impulse Drying Temperature

J. Boerner and D. Orloff

Submitted to
TAPPI Engineering Conference
September 1993
Orlando, Florida

THE EFFECT OF BASIS WEIGHT AND FREENESS ON SHEET PERMEABILITY AND CRITICAL IMPULSE DRYING TEMPERATURE

James Boerner
Graduate Student
Institute of Paper Science and Technology
500 10th Street, N.W.
Atlanta, Georgia 30318

David Orloff
Professor of Engineering
Institute of Paper Science and Technology
500 10th Street, N.W.
Atlanta, Georgia 30318

ABSTRACT

A low thermal mass ceramic coated pressing surface in conjunction with paper webs of low hydrodynamic surface reduce the likelihood of sheet delamination during impulse drying. Darcian permeability measurements of sheets at three basis weights and two freeness levels relates sheet specific surface to the critical impulse drying temperature above which delamination occurs. Impulse drying effectiveness is also determined by comparing outgoing sheet dryness and compression strength to double felted extended nip pressed sheets.

Results indicate that Darcian permeability is affected by basis weight, due to formation of nonuniformities found in light weight sheets and the increasing presence of short fibers and fines in the heavier weight sheets. The nonuniformities, termed macropores, artificially increase the sheet permeability. The macropores allow for higher critical temperature and outgoing sheet dryness by transporting larger quantities of fluid. The higher weight sheets filtered and retained more short fiber than the light weight sheets, hence dryness was maximized at low basis weight and high freeness. All impulse dried sheets achieved higher sheet dryness than those pressed in a simulated double felted extended nip press. Also, it is more advantageous to impulse dry 740 CSF sheets rather than to refine the pulp to 600 CSF and press in a double felted extended nip press.

INTRODUCTION

Impulse drying is a high-intensity drying process first conceived by Wahren (1). In his concept of the process, heat is transferred to a wet paper web during pressing with an externally heated roll. The paper web is pressed between the hot roll and a cold roll under high pressure for a duration of less than one second. A steam layer grows at the hot surface-wet web interface and displaces water towards a felt at the cold roll surface. The key elements of impulse drying are high pressure (>3 MPa), high press roll temperature (>100°C) and moderately long residence times (20-40 ms). Other high-intensity drying technologies, such as press drying, utilize lower pressures and temperatures with pressing times much greater than one second. While similarities exist, impulse drying may be more viable because of its energy efficient water removal and its short residence time, allowing for easy integration into a modern high speed paper machine.

Significant energy savings are projected to be derived from the implementation of impulse dryers (2). The largest savings should come from the fact that an impulse dried sheet contains less water than conventionally pressed sheets and will thus require less energy intensive evaporative cylinder drying. This may be especially beneficial for machines that are dryer restricted allowing for an increase in machine production. It is also projected that because of an impulse dried sheet's greater strength, derived from the sheet's higher density, lower quality and cheaper furnishes, such as recycled fiber, may be used in conjunction with reduced refining energy (2).

Sheet delamination at the nip exit, however, slowed the development of impulse drying (3). While blistering had been noticed in early work (4,5), it did not draw serious concern. This was probably due to the low basis weights (45-90 g/m^2) used in the early studies (4,5) where steam could easily escape the short distance out of a thinner fiber network without causing damage to the bonded fiber network. Impulse drying of sheets made from furnish of freeness below 600 CSF and basis weights of 100-440 g/m^2 caused sheet delamination at low heated surface temperatures (3). Delamination of these higher basis weight sheets were at roll temperatures not unlike those used in hot pressing. Hence, there was little benefit perceived for impulse drying over traditional hot pressing. A number of factors were suspected to be the cause of delamination, but the exact mechanism was not known.

The delamination problem was overcome through the development of a low thermal mass coating for the heated press surface (6,7,8). A low thermal mass pressing surface decreases the quantity of heat conducted to the sheet during the pressing event. This results in lower post press sheet temperatures, hence less steam flashing at the nip opening. Additionally it was found that fiber and network properties such as basis weight, ingoing solids, and degree of refining could be manipulated to manufacture sheets that were more likely to allow easy escape of flashed vapor in the sheet during a drying event by increasing permeability (9).

The work in this paper shows that with a low thermal mass ceramic coated press surface it is possible to impulse dry linerboard grades up to 400 g/m^2 and not induce sheet delamination even at 600 CSF. Measurements of Darcian permeability show that by comparing the hydrodynamic specific surface of paper webs, it is possible to predict the upper limit of roll temperature that may be used to impulse dry a sheet without inducing delamination. In order to emphasize the merits of impulse drying, double felted extended nip pressing is performed at the same impulse to facilitate comparison of post press dryness and sheet compression strength through density development.

EXPERIMENTAL DESIGN

The objective was to determine the critical temperature over a range of basis weights and freenesses in order to extend the impulse drying knowledge base with ceramic pressing surfaces. The sheet weights chosen were 150, 240, and 400 g/m^2 and the freeness 600

CSF and 740 CSF. The range of freeness was chosen to typify the range of freeness used in linerboard mills.

Impulse drying was accomplished on a lab scale MTS press and operated in the same manner as performed by Orloff (9). Specific conditions for these experiments include:

1. Sheets preheated to 85 °C.
2. Extended nip press pulse shape.
3. Impulse = 0.23 MPa seconds.
4. Nip residence time of 40 milliseconds.

All sheets were impulse dried from 49% solids because an impulse drying system will probably be placed after a third press (10). Maximum water removal at the critical temperature was determined for impulse dried sheets and compared to simulated double felted extended nip pressing at the same impulse.

Permeability was measured in order to characterize the sheet internal structure (flow channels) as an indicator of impulse drying performance in future pilot scale trials. Permeability was measured utilizing the apparatus developed by Lindsay (11). In the measurement procedure, saturated sheets were compressed to a known pressure and the sheet caliper used to determine porosity. Flow through the sheet was also measured so that the permeability could be determined at that porosity. Pressure was then systematically increased to obtain a permeability versus porosity graph. From Darcy's law and the Kozeny-Carman equations, permeability was calculated. This, together with sheet solids at known pressures, allows the hydrodynamic specific surface and volume to be determined.

Fiber length distributions were also measured to discover a correlation with hydrodynamic specific surface. STFI index was measured to compare density and strength development between impulse drying and double felted extended nip pressing.

RESULTS

Permeability

Permeability was determined before impulse drying. Experiments have shown that post press permeability does not vary significantly from permeability before impulse drying (12). Therefore, permeability measured before impulse drying is the reported result. Figures 1 and 2 present the results for the three basis weights at 740 and 600 CSF.

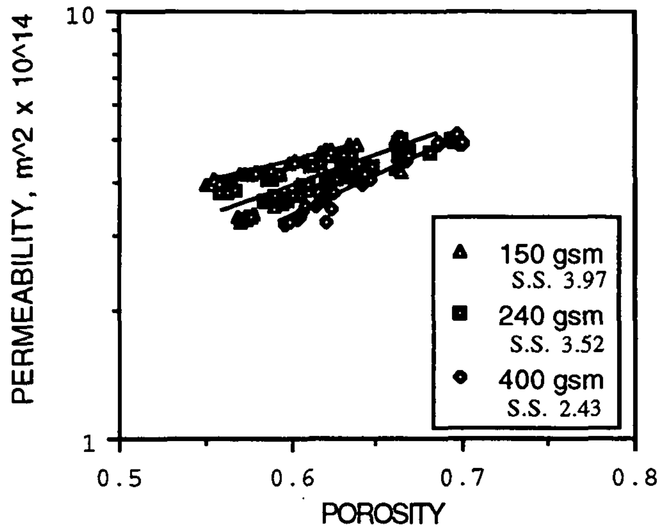

Figure 1: Permeability of 740 CSF sheets as a function of porosity.

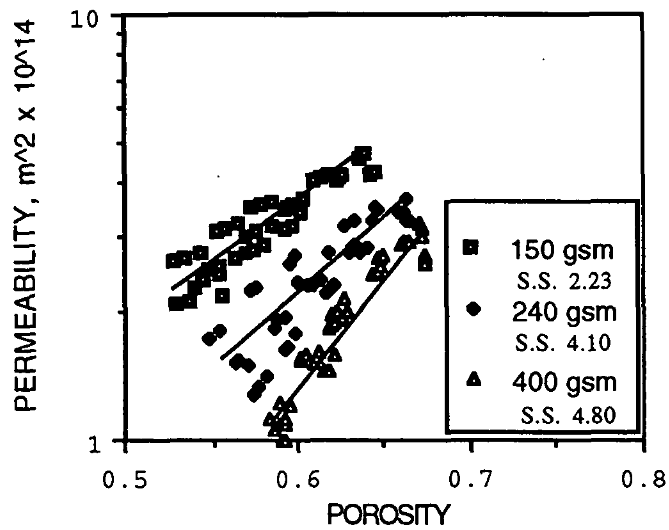

Figure 2: Permeability of 600 CSF sheets as a function of porosity.

Hydrodynamic specific surface for the 740 CSF sheets was nearly basis weight independent. A slight difference is noted between the lowest and highest weight permeability. The 600 CSF samples, on the other hand, exhibit a decrease in permeability and increase in specific surface as the sheets are more refined. Hence, the 600 CSF sheets permeability is dependent on basis weight. It is well established that refining causes both fiber fibrillation and cutting. Both increase the fiber surface area, especially fines as they are colliodal in nature.

An attempt was then made to correlate hydrodynamic specific surface to fiber characteristics. Fiber weight weighted average length and cell wall width were measured while coarseness and perimeter were calculated from the results as shown in Table 1.

Table 1. Mean Fiber Dimensions.

B.Wt. g/m^2	CSF ml	Coarseness mg/100m	Width µm	Perimeter µm	Wt.Weighted Length, mm	Fiber < 1mm %
400	600	34.0	34.1	81.4	2.76	27.92
240	600	31.2	31.5	75.8	2.99	23.21
150	600	30.8	36.8	85.6	3.10	23.72
400	740	33.4	34.8	84.4	3.62	18.71
240	740	33.6	32.4	78.0	3.56	22.10
150	740	31.0	32.6	77.6	3.75	28.82

No significant variation was found in cell wall thickness, coarseness or perimeter. This was expected since the furnish did not change, only the degree of refining. However, a trend of decreasing fiber length was found with increasing basis weight. It seems that with the higher sheet weight, more short fiber was included in the sheet. The measurement of fiber length was done under a microscope, hence the smallness of fines did not allow for their measurement. The differences in fiber length are accurate and reflect the average length in the sheet. Also noted is that refining did indeed shorten fiber length as reflected in the smaller average length of the 600 CSF case compared to the 740 CSF case.

Macropores

Correlating the calculated value of hydrodynamic specific surface with percent of fiber less than 1 mm gives the result seen in Figure 3. In this plot H = 400 g/m^2, M = 240 g/m^2 and L = 150 g/m^2. The 240 g/m^2 and 400 g/m^2 sheets fall along one line and the 150 g/m^2 sheets fall along a line below the heavier basis weights. This is interpreted as evidence for the presence of macropores as postulated by Lindsay (11). The 150 g/m^2 sheets have a permeability that is controlled by macropores. At a given percentage of fibers less than 1 mm, the 150 g/m^2 sheets possess a lower specific surface than the 240 g/m^2 and the 400 g/m^2. This is interpreted that at a certain basis weight macropores no longer pass through the sheet thickness and provide a quick mode of fluid transport.

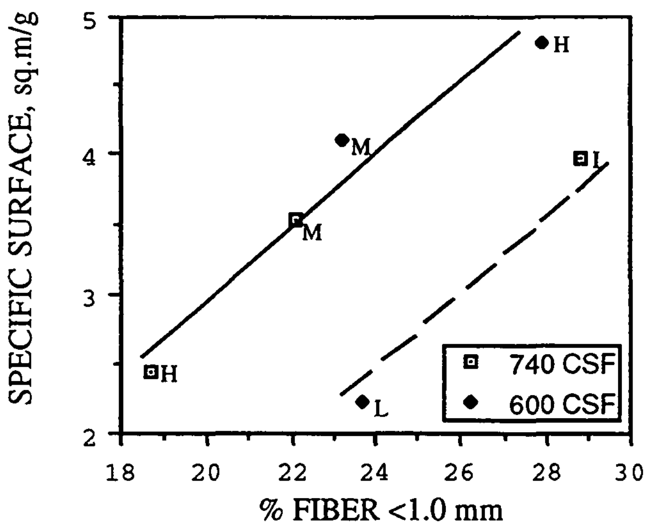

Figure 3: Hydrodynamic specific surface as a function of fiber less than 1mm.

Macropores are postulated to be boundaries between fiber aggregates that pass through the entire Z-direction of the sheet for a low caliper, low basis weight sheet. As sheet weight is increased, however, the macropores are averaged out and the sheet permeability becomes that dictated by the specific surface development of the fiber comprising the sheet. Figure 4 shows how macropores are thought to be represented in a sheet of two different basis weights. As basis weight increases, caliper increases and the macropores are averaged out. The macropores no longer cross the entire sheet caliper and so permeability is controlled by the hydrodynamic specific surface of the fines and fibers in the sheet. Macropores are not yet a fully accepted or understood explanation of the increased permeability of light weight sheets, but a reasonable one. The permeability, whether it be controlled by fiber length and fibrillation or macropores, is a good predictor of impulse drying critical temperature.

Figure 4: Drawings depicting the placement of macropores in a light basis weight sheet and a heavier weight sheet of greater caliper.

Impulse Drying

Comparing the impulse dried sheets to the double felted extended nip pressed sheets reveals that impulse drying achieves greater post press dryness over all sheet weights at both freenesses. A plot of percent incremental dryness in Figure 5 shows the percentage improvement of impulse drying over double felted pressing at the critical temperature. Incremental dryness is defined as the percentage dryness difference of an impulse dried sheet compared to that of a similar sheet that has undergone double felted extended nip pressing.

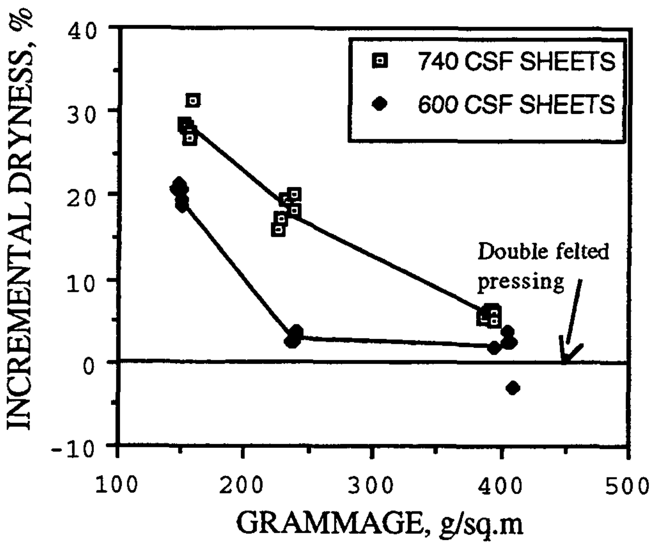

Figure 5: Incremental sheet dryness as a function of grammage at 600 CSF and 740 CSF.

Incremental sheet dryness reveals that higher freeness, lower weight sheets achieve the greatest degree of dryness. This is due to the higher freeness, lower weight sheets possessing the highest permeability, and heavier basis weight sheets containing more water. A heavier sheet with more water will not achieve the same degree of dryness because the steam is not able to propagate into the sheet very far.

On the other hand, the presence of macropores in the light weight sheets provides quick passage through the sheet for 600 CSF and 740 CSF. As sheet weight increases, permeability decreases and the flow of liquid from the sheet lessens for both freeness levels. Water is not able to freely flow through the sheet as the permeability decreases and hydrodynamic specific surface value increases.

There is a limit however to the platen temperature that can be used in impulse drying called the critical temperature. The critical temperature is the highest temperature which can be used to impulse dry a sheet without inducing delamination. The critical impulse temperature is determined from a calculation from specific elastic modulus values obtained from an ultrasonic tester. This is the procedure developed by Orloff (6). A sudden increase in the percent coefficient of variation of the specific elastic modulus (%CVSEM) indicates sheet delamination. This determination is then compared to the observation of sheet blistering during experimentation. A good correlation exists between the observation and the calculation. The critical temperature is found to be highest for the 150 g/m^2, 740

CSF sheets. The higher the permeability, the greater post press dryness that may be achieved. Table 2 presents the critical temperatures determined for each case.

Table 2. Critical Impulse Temperatures.

Basis Weight g/m^2	CSF ml	Specific Surface m^2/g	$T_{critical}$ °C	Sheet Density g/m^3	SEM at T_c MN m/kg
150	600	2.23	351	0.878	0.2126
240	600	4.10	251	0.820	0.2170
400	600	4.80	241	0.779	0.1768
150	740	3.97	497	0.860	0.2050
240	740	3.52	497	0.836	0.2232
400	740	2.43	375	0.794	0.1706
150	600			0.755	
240	600			0.813	
400	600			0.775	
150	740			0.702	
240	740			0.754	
400	740			0.767	

Upon examining the measured sheet density, a trend of increasing density can be linked to increasing platen temperature. Previous work by Orloff (13) showed that the density improvement is due in combination to the mechanical pressing load and the enhanced fiber mat compressibility with platen temperature. It was found that for the 740 CSF sheets the density values of impulse dried sheets was greatest for the 150 g/m^2 sheets comparing to the double felted pressed sheets. A density improvement over that of double felted pressing exists for the higher weights too, but to a lesser degree. Little density improvement was found for impulse dried sheets at 600 CSF. In this case double felted sheets were approximately the same density as those impulse dried, with the exception of the 150 g/m^2 sheets where a slight improvement is seen with impulse drying. The lack of density development for 600 CSF is attributed to the lower platen temperatures used due to the limitations of sheet permeability.

A comparison of incremental STFI index in Figure 6 is given for impulse dried sheets and double felted pressing. Both the 600 CSF and 740 CSF sheets have a decreasing incremental STFI index value as the basis weight increases. The 600 CSF impulse dried sheets do not have a higher STFI index value than the double felted case except for the 150 g/m^2 weight. A greater STFI increment is achieved by the 740 CSF sheets through a higher impulse drying critical temperature and a more permeable sheet, creating a superior density.

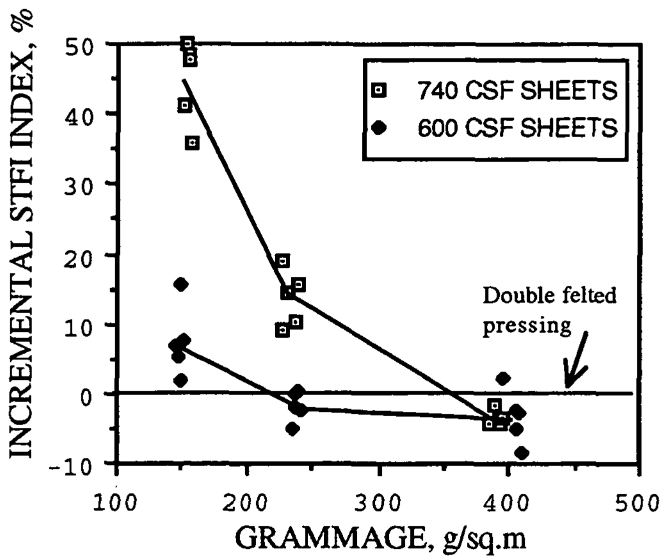

Figure 6: Incremental STFI Index as a function of grammage for 600 CSF and 740 CSF.

Figure 7 allows some interesting conclusions to be drawn. STFI index of double felted pressed sheets and impulse dried sheets for both freenesses and all basis weights are given. From this plot it is seen that it is advantageous to impulse dry a 740 CSF sheet up to a weight of 240 g/m^2. The higher permeability afforded by the high freeness allows higher platen temperatures and subsequent sheet density and strength. A further point can be made. This plot shows that it is beneficial to impulse dry a 740 CSF sheet rather than refine to 600 CSF and send it through a double felted ENP. This is true up to a basis weight of 205 g/m^2, the most common linerboard sheet manufactured. In this case energy may be saved by a lower fiber refining requirement.

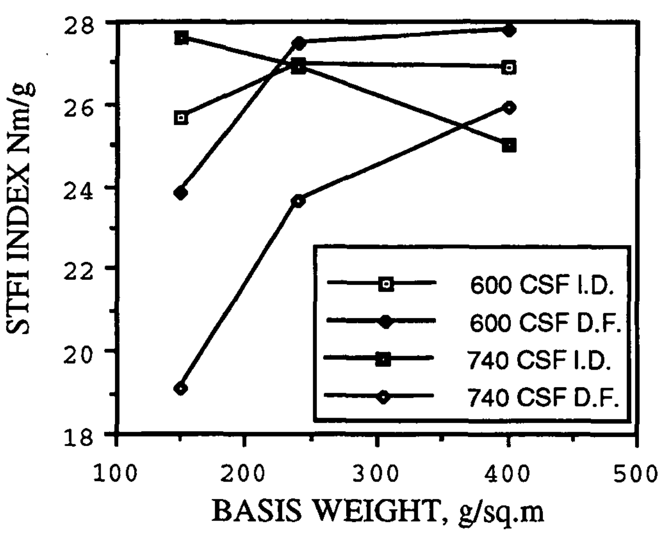

Figure 7: Average STFI Index at the critical temperature as a function of grammage.

CONCLUSIONS

Several conclusions are offered from this study. It has been demonstrated that the low thermal mass ceramic coating inhibits the occurence of delamination for heavy weight grades. Furthermore, impulse drying has the benefit of achieving higher post press sheet dryness over double felted pressing at 600CSF and 740 CSF. The 740 CSF yields the highest dryness and STFI Index values. Impulse dried 740 CSF sheets also exhibited superior STFI Index value up to a basis weight of 205 g/m^2 compared to refining the fiber to 600 CSF and then pressing the sheet in an extended nip press.

A further conclusion stems from the permeability measurements. The permeability was found to be controlled by macropores for light weight sheets. At some unidentified higher sheet weight the permeability is controlled by the degree of fiber fibrillation and fiber cutting resulting from refining. The more permeable sheet achieves the highest dryness values at a given basis weight.

LITERATURE CITED

1. Wahren, D., U.S. Patent #4,324,613 (April 13, 1982).

2. Orloff, D.I.; Sobczynski, S.F., *IPST Technical Paper Series* , "Impulse drying pilot press demonstration: Ceramic surfaces inhibit delamination," No.414 (1992).

3. Crouse, J.W.; Sprague, C.H.; Woo, J.D., *Tappi Journal*, "Delamination-A stumbling block to implementing impulse drying technology for linerboard," 72(10):211-215 (1989).

4. Burton, S.W., An investigation of z-direction density profile development during impulse drying. Ph.D. thesis, The Institute of Paper Science and Technology, Atlanta, GA 1987.

5. Arenander, S.; Wahren, D.,*Tappi Journal,* "Impulse drying adds new dimension to water removal," 66(9):123-6 (1983).

6. Orloff, D.I., *IPST Technical Paper Series* , "Impulse drying of linerboard: Control of delamination," No. 365 (1990).

7. Orloff, D.I., Report 5 for Department of Energy Contract FG02-85CE40738, DOE/CE/40738-T5 "High-intensity drying processes-impulse drying," (1990).

8. Orloff, D.I., Report 3 to Member Companies of IPST, "Impulse drying of linerboard: Evaluation of a prototype ceramic coated press roll," (1991).

9. Orloff, D.I.; Lindsay, J.D., *Proceedings of the Tappi Papermakers Conference* , "The influence of yield, refining, and ingoing solids on the impulse drying performance of a ceramic coated press roll," (1992).

10. Orloff, D.I., Report 4 for Department of Energy Contract FG02-85CE40738, DOE/CE/40738-T4 "High-intensity drying processes-impulse drying," (May 1989).

11. Lindsay, J.D.; Brady, P.H., *IPST Technical Paper Series* , "Studies of anisotropic permeability with applications to water removal in fibrous beds, " No. 417 (1992).

12. Boerner, J.R., M.S. A190 Project, Institute of Paper Science and Technology, "The effect of basis weight on sheet permeability and critical impulse drying temperature," (1992).

13. Orloff, D.I., *Fourteenth Annual Industrial Energy Technology Conference*, "Impulse drying of paper: A review of recent research," p.110-116. (1992).

ACKNOWLEDGEMENTS

Portions of this work were used by J.B. as partial fulfillment of the requirements for the M.S. degree at the Institute of Paper Science and Technology. The financial support of the U.S. Department of Energy and the member companies of the Institute of Paper Science and Technology are gratefully acknowledged for this project.